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EXPERIMENTAL RATE OF PAN EVAPORATION FORECASTS

Gary M. Carter and John S. Jensenius, Jr.

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1. INTRODUCTION

Experimental forecasts of the rate of pan evaporation (RPE) for 66 stations in the National Weather Service (NWS) Western Region will be available on teletypewriter during July through October of 1977. These predictions are for 24-hr amounts and were developed by the Techniques Development Laboratory (TDL) with support from the Western Region Scientific Services Division. The forecasts should be of interest to those NWS forecasters who are involved with agricultural forecasts of parameters related to pan evaporation, particularly in areas of critical water shortages.

2. DEVELOPMENTAL METHOD

We used the Model Output Statistics (MOS) approach (Glahn and Lowry, 1972) to develop our prediction equations for RPE. Figure 1 shows the periods covered and sources of predictors for each cycle. Forecast fields included those from the 0000 GMT cycle of the Primitive Equation (PE) and Trajectory (TRAJ) models and 1200 GMT cycle of the Limited-area Fine Mesh (LFM) and PE models. All the model forecasts were interpolated to the sites of the test stations. These interpolated values and trigonometric functions of the day of year were then screened by the use of a stepwise regression procedure to develop RPE equations for each station. Figure 2 shows the 66 stations for which we derived prediction equations.

The RPE forecasts based on these equations are for amounts of pan evaporation during the 24-hr period immediately preceding the time of observation which is 1200 GMT. Each day, RPE forecasts are made for three periods (12-36 hr, 36-60 hr and 60-48 hr) during the 0000 GMT forecast cycle and for two periods (00-24 hr and 24-48 hr) during the 1200 GMT cycle.

The developmental sample consisted of observations of RPE from July through October 1973, 1974, 1975 and 1976 with each station being required to have at least 180 observations. Most stations had mean RPE observations between .20 and .30 inches, the extreme means being .11 inches at Puyallop, Washington and .42 inches at San Luis Dam, California. Daily observations ranged from no evaporation to slightly over an inch.

3. EQUATION CHARACTERISTICS

The predictors screened by the regression program are listed in Tables 1 and 2. They are divided into several categories based on the cycle and forecast period to which they apply. Further subdivisions are made on the basis of variable type. The cosine of the day of the year and of twice the day of the year were available in all cycles and for all forecast periods.

The RPE equations were limited to 10 predictors with each predictor entering the equation being required to reduce the variance more than one-tenth of one percent. The vast majority of the equations contain the full 10 terms.

The Period 2 RPE equation from the 0000 GMT cycle for Auburn Dam, California is shown in Table 3. The equation reduced the variance by 67% and had a standard error of .06 inches of evaporation. The first predictor entering this equation was the cosine of the day of year which explained 49% of the variance. It was followed by the 48-hr PE mean relative humidity which explained an additional 12% of the variance, and the 36-hr PE 700-mb temperature which explained an additional 2%. The remaining predictors in the equation each added less than 1% to the explained variance.

The standardized regression coefficients, which are a measure of the relative importance of each predictor in the equation, are also listed in Table 3. They are determined by multiplying the regression coefficient of a predictor by the predictor's standard deviation and then dividing by the standard deviation of the predictand. In this example, both the 48-hr PE mean relative humidity and the 36-hr PE 700-mb temperature are about half as important as the cosine of the day of the year. The PE boundary layer and 850-mb U components of the wind appear to be important because of their large standardized coefficients. However, when two predictors are strongly correlated (as these probably are), it is misleading to consider their standardized coefficients separately. In this particular case the standardized coefficients are of opposite sign and tend to cancel each other.

Table 4 is a summary of the reduction of variance and standard error for each of the 66 equations. The overall mean reduction of variance for all stations and all projections combined is .608. There is, however, a considerable amount of variability between stations. The greatest reduction of variance is .847 with the smallest being .271. Standard errors range from .037 inches to .120 inches with only three stations having standard errors greater than a tenth of an inch.

The cosine of the day of the year is overwhelmingly the best singular predictor of RPE. It was selected first by the regression procedure more than 75% of the time and accounted for a large percentage of the total variance explained by the regression equation. The high correlation between the cosine of the day of year and RPE is probably due to the fact that the cosine is particularly well correlated (inversely) with the amount of incoming solar radiation during the period of July through October. The amount of incoming solar radiation is very important in determining pan evaporation.

Humidity predictors also appear to be very important in determining RPE. They were selected second by the regression more than half of the time with the mean relative humidity being the predominant humidity predictor. Other important predictors are the boundary layer potential temperature, 850- and 700-mb temperatures, and winds in the boundary layer and at 850 and 700 mb.

4. MESSAGES AND SCHEDULES

Rate of pan evaporation forecasts are transmitted to the Western Region via RAWARC in three new teletype bulletins (FXUS40/41/42). Values in these messages are in hundredths of an inch. A sample of the FXUS40 bulletin is shown in Figure 3.

Forecasters using this evaporation guidance should be aware that the forecast values are rates of pan evaporation, not evapotranspiration. Also, because the cosine of the day of the year is such an important predictor in many of the evaporation equations, extreme fluctuations from the normal may not often be predicted.

ACKNOWLEDGMENTS

We are very grateful to Rich Wagoner of the Western Region SSD for supervising and coordinating several key aspects of this project. Further thanks are extended to George Hollenbaugh and Fred Marshall of TDL for their computer programming support. We also appreciate the typing assistance provided by Mercedes Bakon and Nancy Harrison.

REFERENCES

Glahn, H. R., and D. A. Lowry, 1972: The use of Model Output Statistics (MOS) in objective weather forecasting. J. Appl. Meteor., 11, 1203-1211.

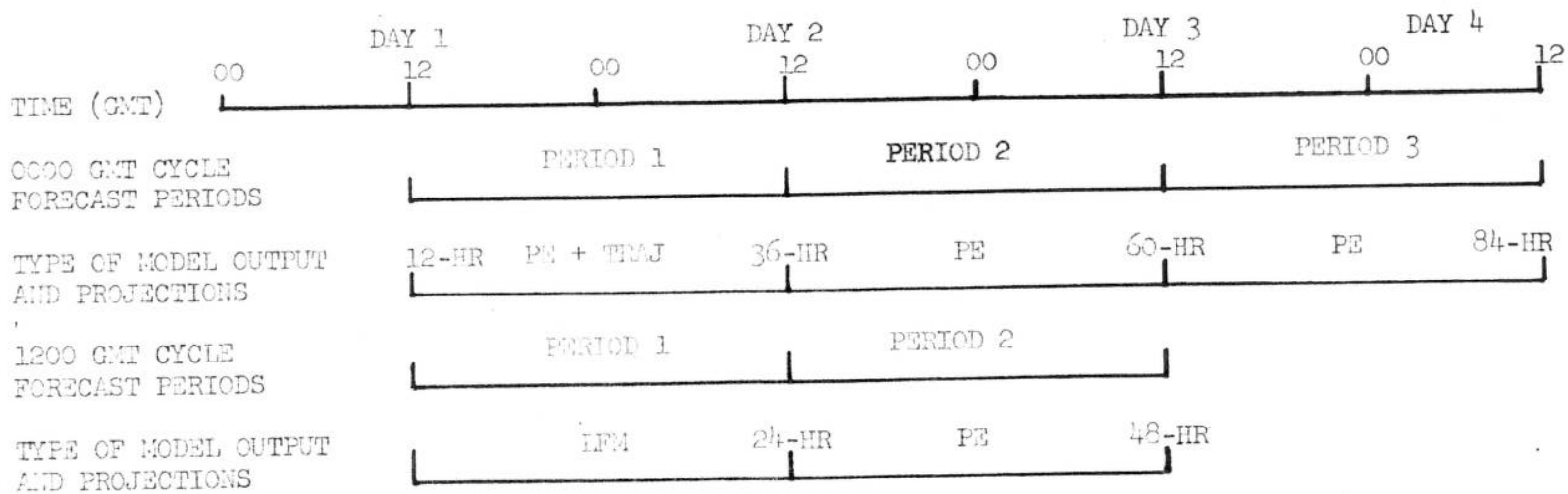

Figure 1. The periods covered by the evaporation forecasts and the source of model predictors for both cycles.

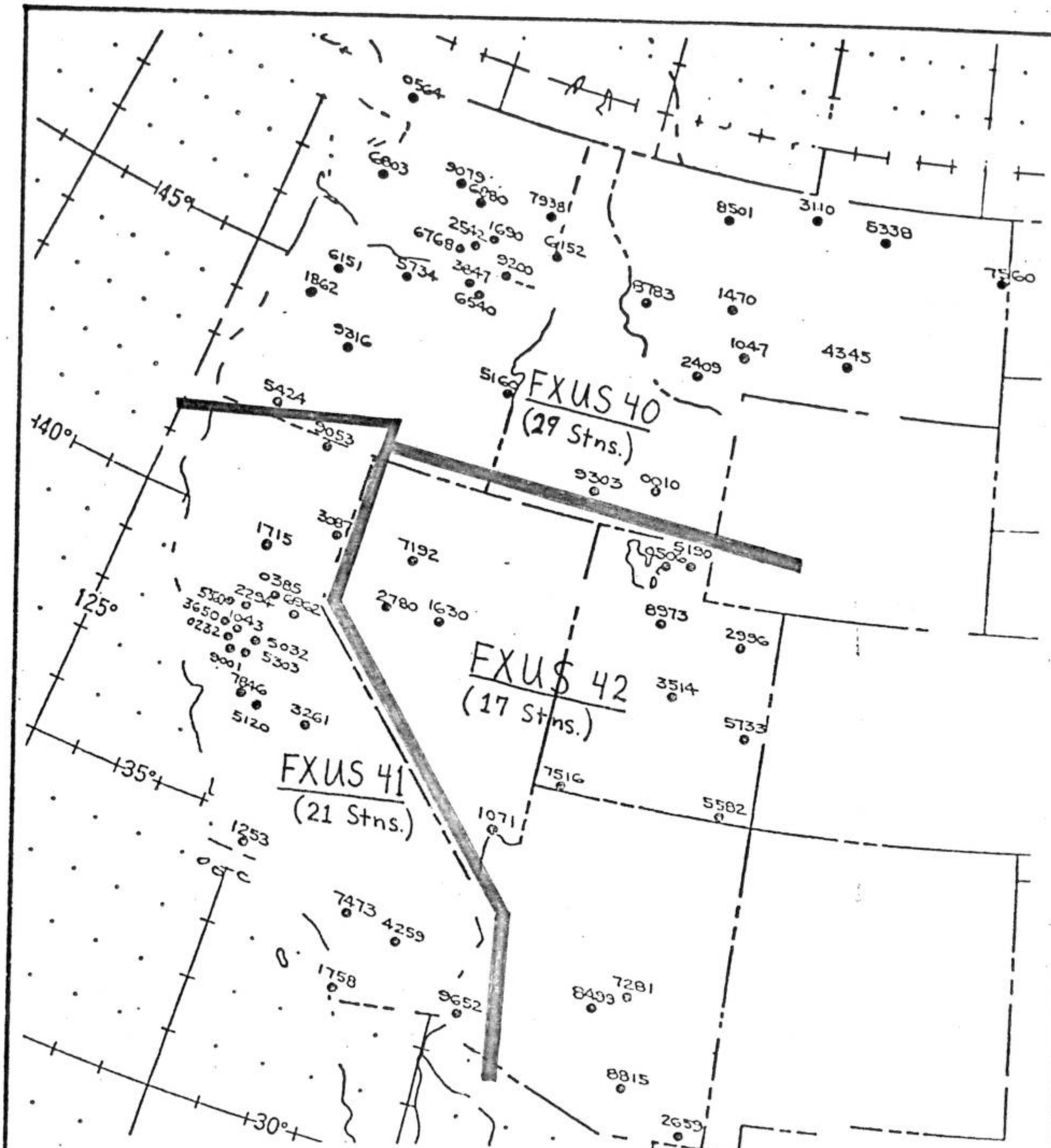

Figure 2. The 66 stations used to forecast 24-hr rates of pan evaporation during the summer of 1977. The bulletins in which the forecasts appear are also indicated, as well as the individual station identification numbers.

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NNNN↓↓A
ZCZC WBC714
FXUS40 KWBC 110000
 FOLLOWING FOR INTERNAL NWS USE--NOT FOR PUBLIC DISSEMINATION
 EXPERIMENTAL RATE OF PAN EVAPORATION FCSTS   7/11/77
 PERIOD- 1200GMT TO 1200GMT
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	12/12	13/12	14/12		12/12	13/12	14/12
0010	28	40	37	6152	22	25	24
9303	28	35	30	1047	21	20	25
1470	23	28	22	2409	21	22	22
3110	21	21	21	4345	34	23	30
5333	14	18	17	7560	21	23	23
8501	18	16	14	8783	18	19	19
1862	20	21	24	3847	32	33	32
5160	31	36	35	5424	27	26	26
5734	38	36	38	6151	19	17	22
6540	33	33	33	9316	23	24	24
0564	17	15	15	1690	31	31	36
2542	23	25	23	6768	27	27	29
6803	13	14	16	6880	24	25	26
7938	29	30	29	9079	30	28	26
9200	31	31	29				

Figure 3. A sample FXUS40 teletype bulletin.

Table 1. Potential predictors available to screening regression program for the development of rate of evaporation equations for 0000 GMT cycle.

0000 GMT CYCLE FOR PERIOD 1
(Forecast Projections of 12, 24, and 36 hours)

Dynamic------	PE 850-mb Height
	PE Surface Pressure
	PE Boundary Layer, 850- and 700-mb U, V and Wind Speed
	PE Boundary Layer, 850- and 750-mb Vertical Velocity
	PE Boundary Layer Vorticity
	PE Boundary Layer Wind Divergence
	PE Boundary Layer 24 Hr Wind Speed Difference
	PE Boundary Layer 24 Hr Potential Temperature Difference
	PE 24 Hr Surface Pressure Difference
	TRAJ Boundary Layer 12 Hr Horizontal Convergence
	TRAJ Surface, 850- and 700-mb Vertical Displacement
Thermal------	PE 850- and 700-mb Temperature
	PE Boundary Layer Potential Temperature
	TRAJ Surface, 850- and 700-mb Temperature
Moisture-----	PE Boundary Layer, Layer 1 and Mean Relative Humidity
	PE Precipitable Water
	PE Precipitation Amount
	PE Boundary Layer Moisture Convergence
	TRAJ Surface, 850-, 700- and surface to 700-mb Mean Relative Humidity
	TRAJ Surface, 850- and 700-mb Dewpoint
	TRAJ Surface, 850- and 700-mb Dewpoint Depression
	TRAJ Precipitation Amount
Stability----	PE 700- to 1000-mb, 850- to 1000-mb, 700- to 850-mb and 500- to 700-mb Temperature Difference
	PE G Index
	TRAJ K Index
	TRAJ Total Totals Index
	TRAJ Surface to 700-mb Convective Instability
Seasonal-----	Cosine of Day of Year
	Cosine of Twice the Day of Year

0000 GMT CYCLE FOR PERIODS 2 and 3
(Forecast Projections of 36, 48, 60, 72 and 84 hours)

Dynamic------	PE 850-mb Height
	PE Surface Pressure
	PE Boundary Layer and 850-mb U, V and Wind Speed
	PE Boundary Layer, 850- and 750-mb Vertical Velocity
	PE Boundary Layer 24 Hr Wind Speed Difference
	PE Boundary Layer Vorticity
	PE Boundary Layer Wind Divergence
	PE Boundary Layer 24 Hr Potential Temperature Difference
	PE 24 Hr Surface Pressure Difference
Thermal------	PE Boundary Layer, 850- and 700-mb Temperature
Moisture-----	PE Boundary Layer, Layer 1 and Mean Relative Humidity
	PE Precipitable Water
	PE Precipitation Amount
	PE Moisture Convergence
Stability----	PE G Index
	PE 700- to 1000-mb, 850- to 1000-mb, 700- to 850-mb and 500- to 700-mb Temperature Difference
Seasonal-----	Cosine of Day of Year
	Cosine of Twice the Day of Year

Table 2. Same as Table 1 except for 1200 GMT cycle.

	1200 GMT CYCLE FOR PERIOD 1 (Forecast Projections of 6, 12, 18 and 24 hours)
Dynamic------	LFM 850-, 700- and 500-mb Height LFM Surface Pressure LFM Boundary Layer, 850-, 700- and 500-mb U, V and Wind Speed LFM Boundary Layer, 850-, 700- and 500-mb Vertical Velocity LFM Boundary Layer Vorticity LFM Boundary Layer Wind Divergence
Thermal------	LFM 1000-, 850-, 700- and 500-mb Temperature LFM Boundary Layer Potential Temperature
Moisture-----	LFM Boundary Layer, Layer 1, Layer 2 and Mean Relative Humidity LFM 850-, 700-, and 500-mb Dewpoint Depression LFM Precipitable Water LFM Precipitation Amount LFM Boundary Layer Moisture Divergence
Stability----	LFM K Index LFM Total Totals Index LFM 500- to 700-mb and 700- to 850-mb Temperature Difference
Seasonal-----	Cosine of Day of Year Cosine of Twice the Day of Year
	1200 GMT CYCLE FOR PERIOD 2 (Forecast Projections of 24, 36 and 48 hours)
Dynamic------	PE 850-mb Height PE Surface Pressure PE Boundary Layer, 850- and 700-mb U, V and Wind Speed PE Boundary Layer, 850- and 750-mb Vertical Velocity PE Boundary Layer Vorticity PE Boundary Layer Wind Divergence PE Boundary Layer 24 hr Wind Speed Difference
Thermal------	PE 850- and 700-mb Temperature PE Boundary Layer Potential Temperature
Moisture-----	PE Boundary Layer, Layer 1 and Mean Relative Humidity PE Precipitable Water PE Precipitation Amount PE Boundary Layer Moisture Divergence
Stability----	PE G Index PE 700- to 1000-mb, 850- to 1000-mb, 700- to 850-mb and 500- to 700-mb Temperature Difference
Seasonal-----	Cosine of Day of Year Cosine of Twice the Day of Year

Table 3. The Period 2 (36-60 hr) rate of evaporation equation for Auburn Dam Project, California for the 0000 GMT cycle.

Predictor	Forecast Projection	Cumulative Reduction of Variance	Coefficient	Standardized Coefficient
Regression Constant	--	--	-1.95	
1. Cosine of Day of Year	--	.4925	- .102	-.453
2. PE Mean Relative Humidity	48	.6152	- .00157	-.244
3. PE 700-mb Temperature	36	.6357	.00526	.205
4. PE Boundary Layer V	60	.6450	- .00359	-.091
5. PE Boundary Layer Wind Speed	48	.6517	.00478	.074
6. PE 850-mb Height	60	.6557	.000474	.134
7. PE Boundary Layer Relative Vorticity	48	.6609	.0208	.123
8. PE 850-mb U	60	.6641	.00534	.115
9. PE Boundary Layer U	48	.6682	- .0148	-.229
10. PE 850-mb U	48	.6723	.0120	.289

Total Reduction of Variance	.6723
Multiple Correlation Coefficient	.8199
Standard Error of Estimate	.0628

Table 4. Reduction of variance and standard error for each station.

Stn. No.	Station Names	0000 GMT Period 1 12 - 36 hr		0000 GMT Period 2 36 - 60 hr		0000 GMT Period 3 60 - 84 hr		1200 GMT Period 1 00 - 24 hr		1200 GMT Period 2 24 - 48 hr	
		RDVR	STD ERR	RDVR	STD ERR	RDVR	STD ERR	RDVR	STD ERR	RDVR	STD ERR
2659	Douglas, AZ	0.377	0.106	0.345	0.108	0.394	0.109	0.376	0.107	0.334	0.108
7281	Roosevelt 1 WNW, AZ	0.497	0.096	0.494	0.096	0.418	0.102	0.498	0.093	0.476	0.093
8499	Tempe UA Cit Exp Sta, AZ	0.764	0.054	0.764	0.055	0.745	0.058	0.767	0.055	0.766	0.055
8815	Tucson U of A, AZ	0.536	0.087	0.489	0.092	0.434	0.093	0.597	0.084	0.489	0.091
9652	Yuma Citrus Sta, AZ	0.690	0.066	0.675	0.068	0.681	0.068	0.698	0.065	0.679	0.068
0232	Antioch Pumping Plt, CA	0.772	0.049	0.749	0.052	0.737	0.053	0.798	0.046	0.764	0.050
0385	Auburn Dam Project, CA	0.738	0.057	0.672	0.063	0.659	0.065	0.759	0.053	0.692	0.061
1043	Brannan Island, CA	0.771	0.062	0.741	0.066	0.726	0.069	0.798	0.058	0.769	0.063
1253	Cachuma Lake, CA	0.740	0.037	0.709	0.041	0.658	0.044	0.751	0.038	0.716	0.041
1715	Chico Univ Farm, CA	0.566	0.074	0.545	0.077	0.533	0.078	0.586	0.075	0.551	0.076
1758	Chula Vista, CA	0.520	0.038	0.476	0.040	0.436	0.042	0.553	0.039	0.489	0.040
2294	Davis 2 WSW Exp Farm, CA	0.706	0.064	0.604	0.076	0.603	0.075	0.731	0.061	0.667	0.066
3087	Fleming Fish & Game, CA	0.790	0.045	0.751	0.050	0.743	0.051	0.819	0.042	0.759	0.048
3261	Friant Govt Camp, CA	0.847	0.048	0.838	0.050	0.824	0.052	0.832	0.049	0.843	0.048
3650	Grizzly Island Refuge, CA	0.771	0.048	0.747	0.050	0.731	0.052	0.767	0.047	0.766	0.048
4259	Indio US Date Garden, CA	0.695	0.077	0.667	0.080	0.645	0.082	0.728	0.072	0.672	0.080
5032	Lodi, CA	0.617	0.073	0.600	0.076	0.613	0.073	0.631	0.070	0.611	0.075
5120	Los Banos Det Resv, CA	0.794	0.082	0.770	0.087	0.745	0.091	0.792	0.079	0.787	0.083
5303	Manteca, CA	0.791	0.047	0.771	0.049	0.768	0.050	0.805	0.045	0.774	0.049
5360	Markley Cove, CA	0.819	0.048	0.777	0.053	0.759	0.056	0.846	0.043	0.816	0.048
6962	Placerville IRG, CA	0.789	0.041	0.731	0.047	0.736	0.048	0.793	0.039	0.765	0.044
7473	Riverside Cit Exp Sta, CA	0.610	0.072	0.549	0.078	0.494	0.083	0.633	0.071	0.577	0.075
7846	San Luis Dam, CA	0.791	0.083	0.777	0.091	0.757	0.095	0.792	0.084	0.782	0.090
9001	Tracy Pumping Plant, CA	0.683	0.094	0.671	0.098	0.645	0.101	0.724	0.089	0.677	0.097
9053	Tulelake, CA	0.556	0.053	0.495	0.057	0.490	0.058	0.604	0.049	0.520	0.055
0010	Aberdeen Exp Sta, ID	0.497	0.077	0.412	0.083	0.401	0.084	0.517	0.077	0.454	0.080
6152	Moscow U of 1, ID	0.517	0.077	0.518	0.080	0.407	0.084	0.516	0.077	0.523	0.081
9303	Twin Falls WSO, ID	0.598	0.056	0.538	0.061	0.532	0.060	0.574	0.050	0.581	0.057
1047	Bozeman 6 W Exp Farm, MT	0.433	0.077	0.379	0.083	0.391	0.084	0.425	0.079	0.386	0.081
1470	Canyon Ferry Pn, MT	0.541	0.062	0.531	0.065	0.460	0.069	0.575	0.060	0.509	0.065
2409	Dillon WMCE, MT	0.417	0.053	0.404	0.054	0.386	0.055	0.499	0.050	0.387	0.054
3110	Fort Assinniboine, MT	0.395	0.082	0.431	0.081	0.387	0.086	0.526	0.077	0.402	0.082
4345	Huntley Exp Sta, MT	0.423	0.077	0.449	0.078	0.421	0.079	0.483	0.076	0.440	0.078
5338	Malta 7 E, MT	0.592	0.058	0.480	0.066	0.519	0.062	0.638	0.055	0.470	0.065
7560	Sidney, MT	0.673	0.051	0.694	0.050	0.683	0.051	0.696	0.050	0.689	0.050
8501	Valier, MT	0.422	0.065	0.443	0.064	0.362	0.068	0.560	0.057	0.445	0.065
8783	Western Mont Br Sta, MT	0.326	0.082	0.302	0.081	0.271	0.088	0.379	0.079	0.281	0.085
1071	Boulder City, NV	0.700	0.080	0.650	0.087	0.578	0.094	0.644	0.088	0.643	0.085
1630	Central Nev Field Lab, NV	0.681	0.075	0.659	0.077	0.660	0.073	0.703	0.070	0.644	0.077
2780	Fallon Exp Station, NV	0.657	0.059	0.639	0.062	0.627	0.063	0.686	0.056	0.677	0.058
7192	Rye Patch Dam, NV	0.579	0.077	0.571	0.079	0.580	0.077	0.610	0.073	0.558	0.079
1862	Corvallis State Col, OR	0.704	0.059	0.654	0.064	0.620	0.067	0.709	0.056	0.668	0.062
3847	Hermiston 2 S, OR	0.542	0.067	0.527	0.067	0.538	0.067	0.671	0.059	0.561	0.065
5160	Malheur Branch Exp Sta, OR	0.743	0.065	0.716	0.069	0.706	0.069	0.774	0.061	0.703	0.070
5424	Medford Exp Sta, OR	0.824	0.041	0.809	0.043	0.791	0.045	0.839	0.039	0.820	0.042
5734	Moro, OR	0.778	0.068	0.748	0.073	0.720	0.078	0.791	0.064	0.766	0.070
6151	No Willamette Exp Sta, OR	0.702	0.060	0.643	0.066	0.615	0.070	0.706	0.059	0.672	0.063
6540	Pendleton Br Exp Sta, OR	0.706	0.068	0.655	0.073	0.632	0.077	0.728	0.061	0.640	0.075
9316	Wickiup Dam, OR	0.745	0.039	0.703	0.043	0.687	0.045	0.765	0.037	0.716	0.041
0506	Bear River Refuge, UT	0.700	0.062	0.663	0.063	0.638	0.066	0.696	0.060	0.664	0.064
2996	Fort Duchesne, UT	0.419	0.093	0.357	0.091	0.397	0.090	0.467	0.083	0.415	0.088
3514	Gunnison, UT	0.726	0.049	0.708	0.051	0.695	0.053	0.752	0.047	0.722	0.049
5190	Logan USU Exp Sta, UT	0.539	0.068	0.529	0.068	0.518	0.070	0.524	0.070	0.540	0.068
5582	Mexican Hat, UT	0.561	0.086	0.557	0.037	0.522	0.089	0.587	0.081	0.563	0.086
5733	Moab 4 NW, UT	0.729	0.065	0.693	0.068	0.696	0.068	0.742	0.063	0.732	0.064
7516	St George, UT	0.440	0.117	0.429	0.118	0.407	0.117	0.455	0.110	0.401	0.120
8973	Utah Lake Lehl, UT	0.474	0.079	0.460	0.080	0.460	0.081	0.527	0.074	0.454	0.080
0564	Bellingham 2 N, UT	0.444	0.056	0.354	0.061	0.349	0.062	0.535	0.052	0.412	0.058
1690	Connell 1 W, WA	0.431	0.089	0.442	0.089	0.447	0.090	0.437	0.085	0.463	0.086
2542	Eltopia 8 WSW, WA	0.721	0.045	0.720	0.045	0.701	0.048	0.733	0.044	0.714	0.047
6768	Prosser 4 NE, WA	0.638	0.060	0.696	0.061	0.700	0.059	0.719	0.058	0.692	0.061
6803	Puyallup 2 W Exp Sta, WA	0.605	0.051	0.567	0.053	0.530	0.054	0.610	0.049	0.571	0.053
6880	Quincy 1 S, WA	0.695	0.055	0.672	0.056	0.659	0.059	0.711	0.052	0.663	0.055
7938	Spokane WSO AP, WA	0.535	0.084	0.489	0.083	0.423	0.094	0.579	0.081	0.510	0.087
9079	Wenatchee Exp Sta, WA	0.530	0.076	0.508	0.077	0.469	0.081	0.622	0.063	0.541	0.075
9200	Whitman Mission, WA	0.757	0.059	0.720	0.063	0.727	0.063	0.767	0.057	0.728	0.063
	Average of 66 Stations	0.621	0.068	0.593	0.071	0.575	0.073	0.649	0.066	0.602	0.070